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Review

Multi-Scale Governance of Sustainable Natural Resource Use—Challenges and Opportunities for Monitoring and Institutional Development at the National and Global Level

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Abstract: In a globalized economy, the use of natural resources is determined by the demand of modern production and consumption systems, and by infrastructure development. Sustainable natural resource use will require good governance and management based on sound scientific information, data and indicators. There is a rich literature on natural resource management, yet the national and global scale and macro-economic policy making has been underrepresented. We provide an overview of the scholarly literature on multi-scale governance of natural resources, focusing on the information required by relevant actors from local to global scale. Global natural resource use is largely determined by national, regional, and local policies. We observe that in recent decades, the development of public policies of natural resource use has been fostered by an "inspiration cycle" between the research, policy and statistics community, fostering social learning. Effective natural resource policies require adequate monitoring tools, in particular indicators for the use of materials, energy, land, and water as well as waste and GHG emissions of national economies. We summarize the state-of-the-art of the application of accounting methods and data sources for national material flow accounts and indicators, including territorial and product-life-cycle based approaches. We show how accounts on natural resource use can inform the Sustainable Development Goals (SDGs) and argue that information on natural resource use, and in particular footprint indicators, will be indispensable for a consistent implementation of the SDGs. We recognize that improving the knowledge base for global natural resource use will require further institutional development including at national and international levels, for which we outline options.

Keywords: natural resource governance; decoupling; abiotic and biotic resources; Sustainable Development Goals (SDGs); consumption and production; Four Footprints

1. Introduction

The post-2015 development agenda strongly suggests that achieving the Sustainable Development Goals will depend on the sustainable management of natural resources. Many goals and targets directly address natural resource management (target 12.2), waste minimization (target 12.5) and decoupling of economic growth and natural resource use (target 8.4) [1]. The interconnected nature of the SDGs requires natural resource management policies to go beyond traditional approaches, such as management and governance of a field or a forest by a local community and how to avoid the overuse of a fishing ground. In a globalized economy, the sustainable use of natural resources requires simultaneous monitoring and management at different scales, from local to global. Policy formation and management practices will require sound scientific information. Monitoring is essential for the success of existing and new policies and business strategies in order to provide orientation and direction for decision makers. While the literature of traditional natural resource management in different localities and communities is rich, there is a gap in analysis that addressed the national and global scale of resource governance and a need to further explore the multi-scale characteristics of resource use systems, governance arrangements and policies. To fill this gap in the scholarly literature, this review article provides an overview of the action arenas which shape natural resource use and the information required for actors to facilitate a transition to more sustainable resource management across multiple scales and between countries. To improve natural resource management, new institutional capacity and governance arrangements will be needed. In particular, we (1) emphasize the need of institutional development and associated capacity building opportunities for improving national and global scale resource management and (2) outline the information base that would foster knowledge-based decisions.

The use of many natural resources such as primary materials (ores, minerals, energy carriers, and biomass) is mainly regulated by national property rights and the ownership of land containing natural deposits, agricultural fields or forested areas [2]. Responsible use by those owners in mining, agriculture and forestry are subject to voluntary standards of good practice and varying local to regional legal requirements for environmental quality standards, labor conditions and social acceptance. The environmental and social implications of the subsequent material flows through manufacturing, final production, consumption, recycling and final waste disposal are then subject to specific regulatory requirements for ensuring human health and environment integrity by regulating, for example, the release of pollutants to air and water and final waste deposition by companies and communities. These regulations mitigate possible negative impacts of natural resource flows at the local to regional scale.

As global natural resource use grows and environmental impacts increase, these approaches are insufficient to keep the overall magnitude of global natural resource use and the resulting environmental and social impacts within a safe operational level corridor [2–4]. While many businesses in natural resource sectors now operate globally, the governance of natural resources and material flows at national, regional and global levels is still in its infancy. In the absence of an international or even global institution, global natural resource use consequences are currently managed by national and sub-national policies. A growing number of countries have developed natural resource policies that aim to decouple economic growth and human development from natural resource consumption. While the proximate goal of these national policy makers in countries that have ambitious resource efficiency policies is to enhance the competitiveness of their economies and become more independent of global markets for natural resources, they also act in the interest of the global environment. Some countries have established goals, objectives, targets and use indicators to measure progress. The new SDGs require all countries to measure progress towards sustainable natural resource use which will entail more ambitious policy efforts in many countries to drive responsible behavior by businesses, public consumers and households.

An essential component of effective policy making is the orientation towards overarching goals and the measurement of progress through indicators [5,6]. For global natural resource use, we argue that indicators for production and consumption of natural resources for the use of materials and energy, land and water and the disposal of waste and GHG emissions, and in particular indicators derived from national Material Flow Accounting (MFA), should play a central role, because they report major environmental pressures and can be applied across sectors and for all geographical scales, from local to global. Examples of good practice and identifying win–win options for people, economy and the environment, and the guidance provided by indicators and targets for assessing progress, will be essential to enable more sustainable use of global natural resources across countries.

A definition of natural resources is an important starting point to devise monitoring systems and would include abiotic materials (fossil fuels, metal ores and minerals), biomass, energy, water, air and land. Some include ecosystem services such as biodiversity and life-sustaining functions of earth and ecosystems including climate stability. For our purpose we will adhere to a definition which excludes a broader suite of ecosystem services and relies on a definition of natural resources which is compatible with national accounts and the System of Environmental and Economic Accounts (SEEA) framework.

Global consumption of natural resources has been growing rapidly since the 1970s and has led to a multitude of environmental impacts including depletion of natural resources, acidification and eutrophication of land and water, waste problems, air pollution and climate change. Increasing extraction of natural resources has also resulted in increasingly negative social repercussions. The annual global extraction of materials grew from 30 billion tonnes in 1970 to 70 billion tonnes in 2010. Material extraction has accelerated since the year 2000, at a time when the global economy and population growth have slowed [2]. With a growing world population and a growing middle class, especially in developing countries, business as usual suggests that 125 billion tonnes of materials in 2030 and 180 billion tonnes of materials in 2050 will be required to fuel the global economy [7]. When materials that are mobilized in the process of materials extraction, but not further used economically are included, the projected overall extraction of primary materials in 2030 ranges between 300 and 335 billion tonnes [4]. The number of local social conflicts caused by environmental disturbances and community displacement because of fast-expanding extraction infrastructure, refining and manufacturing activities and final waste disposal is rising and of growing concern (see Ejolt project: http://www.ejolt.org). It should be noted that these local conflicts, for instance when involving extractive industries, are largely driven by demand in distant regions and result from patterns of manufacturing and consumption which have become unsustainable.

Water consumption is expected to increase in all sectors of the global economy. Growing water withdrawals for agriculture and energy will further exacerbate water scarcity in many regions and countries. A business-as-usual climate scenario projection indicates that a 40% water deficit will occur globally by 2030 [8].

Fast-increasing land requirements for agriculture, timber production, mining, human settlements and transport infrastructure will significantly change land cover, affect hydrology and contribute to additional loss of biodiversity and increasing greenhouse gas emissions. From 2005 to 2050, unrestricted expansion of built-up land will more than double, reaching 260 to 420 million hectares worldwide [9]. To some extent this will occur at the expense of fertile agricultural land. The growing world population, changing diets, a stagnation of yield increases and soil degradation will lead to a significant expansion of cropland at the cost of grasslands, savannahs and forests, mainly in tropical countries. From 2005 to 2050, business-as-usual gross expansion might be in the range of 320 to 850 million hectares [3].

Such tremendous change will demand large investment into new governance mechanisms to facilitate sustainable natural resource use. In this article, we will describe for the first time key challenges for monitoring and institutional development at the national and global level in order to support multi-scale governance towards sustainable resource management. We combine literature review with insights from our work as members of the International Resource Panel (IRP) hosted by the United Nations Environmental Programme. We start with reviewing the current situation of the different levels of natural resource management in order to provide an overview rather than to be exhaustive. We will then focus on global resource management by (supra-)national governance.

We will highlight headline indicators which we think are key for monitoring natural resource use, i.e., materials, energy, land and water. We will discuss resource-related strategies and information required to successfully pursue the SDGs and will point out that those indicators can help monitoring and designing progress towards sustainable production and consumption which we deem central for reaching most of the SDGs with minimum of trade-offs. Against this background, we will outline the needs and options for institutional development to improve the knowledge base and proceed towards sustainable natural resource management at multiple scales and then focus on deficiencies at the national and global levels.

2. Different Levels of Resource Management

There are different levels of managing natural resources which are, however, interlinked. In the following we progress from local management and to higher scales towards the global scale. We will demonstrate that an action at a lower scale is necessary but not sufficient for guaranteeing the sustainable use of natural resources on a global scale. Towards this end, governance is also required at higher scales, and should be integrated across scales, and for that purpose adequate information is needed.

2.1. Agriculture, Forestry, Fisheries and Mining

Traditionally, natural resource management has focused largely on the local management of a farm, forest, fishing ground or mine. Key actors in this context have been individuals, cooperatives or companies of farmers, foresters, fishermen and mine owners and workers. For land-bound resources, there are principles, standards and guidelines for good agricultural [10] or forestry practices [11], for managing freshwater fisheries (e.g., [12]) and for mining [13,14] which consider sustainability aspects of how to prolong the use of natural resources, extend local productivity and minimize undesired side-effects. Marine fisheries are often subject to significant competition leading to overfishing [15]. In this context, institutions are necessary to mitigate competition between land users and ocean fisheries, and to control impacts from primary sectors—including agriculture, forestry, inland fisheries and mining—beyond the fence. For instance, limits of pollution to ground or surface water from cropping fields or from mining waste are set by institutions at a higher scale (e.g., river basin management or country legislation). Nevertheless, even if all activities of primary natural resource extraction and harvest were conducted according to good practice, growing demand for land-based natural resources and inefficient use in further processing could lead to growing competition for land, inducing land use change and related impacts at a larger scale, a phenomenon which can already be observed with current practices where growing demand for food and non-food biomass leads to the expansion of cropland at the expense of grasslands, savannahs and forests [3].

2.2. Manufacturing Companies

Companies have an interest in saving costs and optimizing their economic performance. Thus, they have a vested interest in decoupling their profit from the use of materials, energy, water, and the generation of waste and emissions within the company. This incentive is significantly influenced by external factors (markets and governments) and dependent on the potential for cost savings. Companies are increasingly implementing material and energy saving measures, which are often more effective if supported by provincial (state) or national government frameworks and policies [2]. The main focus is usually on material, energy and water efficiency within the company; these are part of standard reporting [16]. In the course of extended producer responsibility and the growing importance of social license to operate, an increasing number of companies are looking beyond the fence in order to comply with sustainability requirements [17] defined at a higher scale, by applying a whole life-cycle perspective and getting involved in product chain management, for instance, to eliminate deforestation in the tropics from timber supply [18].

2.3. Private Households

A private household has an interest in improving subsistence and well-being, enhancing income and avoiding losses of investment goods or through unnecessary wastage. Households also react to price signals which are determined by external factors. Low-income households are often deemed to use natural resources inefficiently, while wealthy households can choose efficient products but may consume more of them, a pattern which resembles relations between countries [19]. Consumer behavior critically depends on information about what alternatives are available on the market but such information is often incomplete. Households are usually rather distant from resource extraction activities. Product price is the main information provided, sometimes supplemented by environmental performance data for products (e.g., energy consumption of electric appliances). Price is, however, not always the single most important consideration of consumers and additional information is usually requested. In response to consumer awareness a multiplicity of product labels has emerged. While they may provide certain useful information, the overall effect is often confusion rather than clarity [20,21]. Orientation towards key criteria seems lacking for many product labeling systems.

2.4. Public Procurement

Public procurement induces significant consumption of durable and nondurable goods. Economic efficiency is usually the highest priority, while guidelines to sustainable procurement have been crafted and are being refined (e.g., [22]). As the administration serves the public interest and performs government functions, policy goals and targets, for instance on material and energy efficiency, could directly be implemented, if product-related information was available or made compulsory. Indeed, environmental product declarations (EPDs) [23] are increasingly required for goods that are publicly purchased. The criteria are derived from LCA schemes. While most LCA impact indicators such as Global Warming Potential are well established, other categories such as Abiotic Resource Depletion lack consensus among LCA experts [24]. This lack of consensus is further exacerbated by a lack of understanding by those who are expected to use and interpret such information. Life-cycle-wide material efficiency is not yet considered in EPDs. Initial engineering standards to measure cumulative raw material requirements have just been drafted [25]. In the absence of overarching resource policy goals and corresponding guidelines for public administration, public procurement may result in unsustainable natural resource use despite good intentions.

2.5. Product Chain Management

This type of "horizontal" resource management extends beyond the boundary of a farm, company, household or public consumer. It is typically established by companies which have an interest in the life-cycle performance of their products. This interest is fostered by legal requirements of countries or voluntary commitments of companies and demanded by a growing proportion of wealthy consumers who want to buy more sustainably produced products. Product chain management may be supported by life-cycle-costing and LCA, thus facing the same limitations discussed above for EPDs, which represent a specific form of product certification. In general, certification schemes for selected products may provide an information chain which reaches from the field, forest, fishing ground or mine to the final consumer. Yet, under most circumstances only a limited share of product groups are subject to certification and labeling [3]. Criteria for certifying agricultural products mainly focus on direct environmental impacts of cropland management (e.g., [26]). National resource efficiency may only be fostered when appropriate indicators are recorded on the basis of whole product life cycles. Moreover, unbound consumption of efficiently produced goods could lead to exceedance of safe levels of global resource consumption (as in the case of first generation biofuels), making control mechanisms necessary at higher scales.

2.6. River Basin Management

Integrated resource management at the level of a river basin considers the flows and stocks of water bodies together with all relevant activities which depend upon or may influence the quantity or quality of the water throughout the system [27]. The effluents from agriculture and industries, as well as households or sewage treatment, need to be controlled in order to ensure appropriate water quality. The relevant actors reside in agriculture and forestry as well as in cities and have to comply with standards which are often set by institutions at higher levels (sub-national or national or supranational). The implementation of policies and regulations, however, and the desired practice often depends on specific conditions within the river basin, in particular water availability. Globally, water consumption is mainly caused by agriculture (70%–80%) though energy and material supplies also require significant amounts of water [28] which implies that higher energy and material efficiency in industry and households can contribute to better water efficiency at a higher spatial scale. This in turn requires monitoring and policies to foster material and energy efficiency across the whole economy.

2.7. City and Regional Planning

Spatial planning in cities and regions mainly decides where certain infrastructure, buildings or service facilities are going to be built and how they are connected by transport and communication facilities and utilities. Urban planning has little impact on sustainability outcomes at the building scale, which relies on environmentally focused building standards. The question of whole-of-life-cycle performance has attracted growing interest from city management and urban planners. The planning of infrastructure for transport, energy supply and water management of whole urban areas is often informed by considerations of resource requirements and carbon emissions within and beyond the city boundary [29]. Besides green field development, the maintenance and refurbishment of existing building stocks has become increasingly important, aiming for increased recycling (urban mining) and higher resource efficiency and lower carbon emissions at different levels within cities. Standards for infrastructure, housing and water management are, however, often set by institutions at higher scales including state and national governments. Improving the performance of cities to the benefit of overall sustainability requires avoiding shifting problems to urban hinterlands and other regions [30]. Resource efficiency may only be fostered effectively if adequate life-cycle-based indicators are applied and reference measures are provided for all cities within regions and globally to assess progress towards sustainable resource use.

2.8. National Resource Management

National resource management aims to improve the performance of countries, in terms of a consolidated physical basis. The main interests of countries that rely on natural resources from abroad include increased supply security, greater resilience to volatile world market prices and enhanced international competitiveness [31]. The latter may be improved by higher resource efficiency, which leads to cost savings and is enabled by innovation and technological progress [32]. An added benefit is the lower environmental burden achieved by natural resource conservation. Some countries, which have spearheaded national resource efficiency policies and programs, also intend to reduce their burden on other regions and to contribute to lower, safer and fairer resource use worldwide [31,33]. National governance in pursuit of reducing global use of natural resources becomes more and more important. Whether this leads to more sustainable global resource use is informed by performance indicators which capture problem shifting between regions and sectors and benefit from targets for sustainable natural resource use levels. It also requires that indicators be applied consistently across multiple scales to inform regional, national and local resource management. In recent decades growing diversification of resource exporting and importing countries has occurred which has meant that countries which depend on resources from abroad have favored resource efficiency policies while resource exporting countries usually face a more adverse domestic policy context for resource efficiency policies.

2.9. Global Resource Management

Resource management by global institutions is still the exception and limited to only a few areas. For instance, in the Antarctica treaty [34] countries agreed not to use the continent for natural resource extraction, and the UN Convention on Biological Diversity [35] laid out principles and established instruments aimed to halt global loss of biodiversity in terrestrial and ocean ecosystems, i.e., within domestic as well as international waters. With regard to globally sustainable *use* of natural resources, including within production and consumption systems, there is still no international convention.

2.10. Cross-Level Effects through Markets and Market Signals

All actors across the levels described above are linked to markets through their economic activities. The role of markets and the ways in which various governance levels are using them in managing natural resource use are extremely important. The smaller the scale, the narrower the market segment influenced, although new technologies and management practices often start in niches. The higher the scale, the more pronounced are economic instruments when designed to incentivize more efficient and sustainable use of natural resources.

Multi-scale natural resource governance is already happening, at different paces and with different reaches at the various levels, with the major objective of mitigating environmental burdens associated with various natural resource uses. The challenge persists that at each level sustainability criteria will have to be considered in a consistent and synergistic way. Information is required to inform about and help minimize problem shifting across sectors and regions. For this purpose, vertical consistency across scale is necessary and indicators need to capture total natural resource use of lower scale actors and processes. For instance, national material flows comprise the material flows induced by all companies within a country. Capturing horizontal shifts between countries requires consideration of indirect material flows associated with trade, i.e., applying a whole-of-product-life-cycles perspective and commensurate system boundaries for the indicators.

Global natural resource consumption is significantly influenced by national policies. It is, therefore, worthwhile to consider a country's natural resource use and resource efficiency policies and develop options for institutional and capacity strengthening which can support national governments, especially in developing countries, to help steer global resource use towards sustainability by virtue of national policy settings.

3. Global Natural Resource Management by (Supra-)National Governance

3.1. Goals of Resource Policies

National resource policies pursue three complementary objectives: access to natural resources, increasing the efficiency of resource use, and ultimately adjusting the overall scale of natural resource use through technical and social innovation towards more sustainable levels.

A Resource access policies: The goal is to ensure continuous and timely supply of affordable natural resources. Within a country, spatial planning and property rights arrangements, for instance, regulate exploration and mining licenses and often prevail above competing land uses. Supply security is guaranteed through long-term contractual arrangements between countries and businesses, and economic incentives are in place to support supply.

B Resource efficiency policies: The objective is to enhance decoupling of economic growth and natural resource consumption. Often, the underlying objective is to become more independent of imports of natural resources, and to enhance competitiveness by saving costs and by driving innovation. Thus, economic benefits are the key incentive, while the reduced environmental burden is readily accepted as a bonus.

C Sustainable natural resource use policies: The goal would be to use natural resources not only efficiently but also in an internationally fair, secure and environmentally safe manner for the provision of improved living standards and well-being. The objective is to complement resource efficiency measures with additional measures that avoid rebound effects and enable a shift towards resource sufficiency in terms of absolute levels of natural resource consumption.

The more advanced natural resource policies in a country are, the more aspects they integrate.

As a consequence, sustainable natural resource policies go beyond the scope of single government agencies and require the collaboration of a number of agencies, preferably coordinated by a lead agency. To be successful they rely on capacity to integrate the objectives of different policy domains such as economic, environmental, and urban and land use policies. If they are mainstreamed into all areas of policy they provide direction to all government policies. They require that the natural resource use consequences of all government policies and plans be assessed. They are often expressed as high-level policy agendas that steer sectoral policy efforts towards the goal of sustainable use of natural resources.

One such example is the raw material initiative of the European Union [36] which comprises three pillars, two of which aim to secure supply, whereas the third aims to increase resource efficiency and thus enhance independence from foreign supply. The latter is particularly supported by the flagship initiative for a Resource Efficient Europe 2020 [37] and the roadmap for a Resource Efficient Europe [38]. The dualism of resource security and resource efficiency policies can be observed in many countries. While the former, in principle, encourages an increase of natural resource extraction and harvest in some parts of the world, the latter tends to mitigate demand and has the opposite effect. Meanwhile, efficient—or smart—use of material resources has been formulated as a policy goal in China, Japan, South Korea, the EU, Austria, Estonia, France, Finland, Germany, the UK, Hungary, Poland, Portugal, Romania and Slovenia, with quantitative targets on resource productivity set by nine countries [31,33]. Japan and Germany are also frontrunners with regard to policy programs fostering resource efficiency throughout the economy, within industries, public administration and households.

Sustainable natural resource use policies are more difficult to determine. While the aspect of international responsibility of avoiding overexploitation of natural resources is acknowledged by several countries at the general policy level, quantitative indicators of progress—in particular targets on absolute resource consumption—are still limited. Examples include the objective of reducing extraction of scarce aggregates in Sweden, Denmark and the UK, mainly driven by domestic resource constraints. The Austrian government has set a target of reducing domestic material consumption by 20% by 2020 compared to 2008 levels and has established a program for policy implementation. The government of Italy announced a target to reduce natural resource requirements by 90% by 2050 using a comprehensive measure of natural material resource use (The Total Material Requirement comprises all primary materials extracted domestically or abroad to support the production and consumption activities of a country, including both used and un-used extraction (the former represents the products sold by mining, agriculture etc., while the latter represents the extraction which remains there as a waste (such as overburden) and the excavation for construction and infrastructure building.). Policy implementation is not yet established. Switzerland aims to reduce consumption to environmental "footprint one" (for country references see [33]). Discussions around setting targets for absolute reductions in natural resource consumption are ongoing in various countries.

Identifying appropriate policy targets for natural resource consumption is still in an early phase, as the scientific indications of which level of natural resource use would be globally sustainable represent a range—or corridor—rather than distinct and precisely determinable values [4]. In addition, any such policy target would reflect normative settings of social acceptability of environmental change rather than pure scientific deduction. The discourse on potential targets is ongoing, and the selection of key indicators seems to require a longer policy learning process.

Most countries with explicit resource policies so far aim at relative decoupling of natural resource use and economic growth. This implies that resource consumption might further grow in absolute terms, although at a lower rate than GDP. Policy priorities seem to vary. Wealthy countries which are net importers try to become more independent from imports and reduce their production costs.

Developing countries put emphasis on improving income conditions. For the build-up of infrastructure, material investments are required, and in low-income countries, the key challenge is increasing resource efficiency throughout the economy rather than restricting material consumption levels, which are still much lower on a per capita basis than in wealthy industrialized countries [39]. Towards the future, with rising income of the poor and growing well-being throughout the world, strongly increasing resource productivity may help to balance the consumption of natural resources at an environmentally safe and socially fair level [19]. Emerging economies with rapid economic growth, such as in the Asia-Pacific region, are especially challenged [40]. For countries like China further progress towards decoupling is a priority. The recent Chinese 13th Five-Year Plan set mandatory targets for increasing productivity of energy and water related to GDP by 15% and 23%, resp., and CO_2 emissions per unit of GDP shall decrease by 18% (2015–2020), while the annual GDP growth rate should be larger than 6.5% [41].

While most countries are net importers of natural resources [2], a few large countries such as Australia, Canada, and Russia, parts of Latin America, Africa and Asia with significant endowment of natural resources are, and might continue to be, net exporters. In the course of falling prices for fossil fuels and metal ores in recent years, it has become clear that their economies would also benefit from becoming less dependent on the export of natural resources, for instance, through diversification, recycling and boosting service-based domestic economic activities.

3.2. Recent Resource Policies emerged from a Comprehensive Systems Perspective

3.2.1. Interaction of Research, Statistics and Policy

Resource access policies have a long tradition since the beginnings of human civilization. They existed in hunter–gatherer societies, early agricultural settlements, and the large Greek and Roman empires, which caused the colonization of whole continents through European powers and were the source of military conflict in the 20th century. Historically, military force and economic power have always been essential elements of resource access policy. While the conflicts often result from many causes and complex interactions, violent conflicts still arise from quarrels over or fueled by the desire to access natural resources [42,43].

Much more promising, as a means to overcome conflicting policies and move towards more peaceful development, is the development of resource efficiency policies and policies for sustainable resource use.

Resource efficiency policies have been developed against the background of an enlarged systems perspective in particular in the domain of material flows. In the second half of the 20th century environmental policies focused on the control of pollutants and emissions to air and water as well as safe waste disposal and focused on end-of-pipe solutions [32]. In the early 1990s, national material flow accounts provided a more comprehensive picture of the physical economy. These are based on the notion that natural resource inputs determine waste and emission levels and are associated with environmental impacts along the production–consumption chain from extraction to final disposal. The national economy perspective is comparable with economic accounting. The territorial perspective was extended by the life-cycle perspective based on LCA of products, so that foreign trade could be traced back to resource flows [44]. The new approach informed and enabled resource efficiency policies and a new focus on decoupling of natural resource inputs from economic growth. This resulted from a societal learning process.

The collaborative learning process involved science, statistics and the policy community and triggered a new level of ambition and effort by all players involved (Figure 1). In the early 1990s, independent research in Japan, Austria and Germany provided first national material flow accounts (for historical references see [44,45]. In Japan, researchers at the National Institute for Environmental Studies produced the first flow chart of material throughput of the national economy for the White Book in 1992, which provided the systems perspective for developing the 3R strategy (reduce, reuse, recycle) in the subsequent decade. In Germany, research at the Wuppertal Institute provided accounts which were adopted by the German Statistical Office and laid the basis for regular reporting. Indicators derived from economy-wide material flow accounting were used in studies such as Sustainable Germany [46] which proposed targets on resource productivity to operationalize the factor 4–10 concept. Those indicators with more moderate targets were then adopted into the first draft of the German Government's environmental policy program, which was introduced in the German Sustainability Strategy launched in 2002. In Austria a similar institutional interaction between academia, the environment department and the national statistical office resulted in the implementation of MFA accounts into regular statistical reporting, and later towards resource efficiency policy targets.

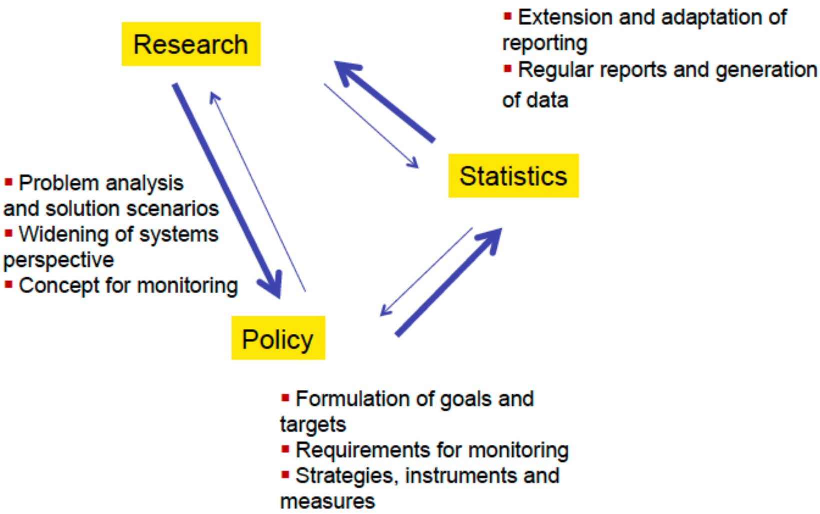

Figure 1. The societal learning and inspiration cycle involving research, policy and statistics.

Policy demand for information derived from economy-wide material flow accounts was significantly boosted by two international comparative studies [47,48]. Both rising demand and a method which enabled benchmarking of countries triggered the development of guidelines by Eurostat [49,50] and the OECD [51] for material flow accounts and headline indicators. Since 2000, resource efficiency policies have been developed by pioneering countries and regions including Japan, Austria and Germany and the European Union. They have focused on decoupling indicators [33]. The methodology and indicators for economy-wide national MFA are now well established [45]. Figure 1 sketches the collaborative learning that occurred in a new institutional setting involving researchers, environmental ministries and national statistical offices. A positive feedback loop of interest and ambition was created which reinforced the activities in research, policy and statistics. We name the collaborative learning that raised the engagement of all actors and led to outcomes that no individual actor could have achieved alone the "inspiration cycle". It enabled new insights through challenging outdated views and creating new opportunities.

In 2007, the International Panel for Sustainable Resource Management (now called the International Resource Panel, IRP) was established providing an international forum of independent research and review. Although not part of an intergovernmental process, the panel interacts with a steering committee including representatives of member countries' governments. The panel experts have produced a multitude of studies, which focus on key problems, sectors and natural resources, outline future visions and describe possible policies and measures to facilitate a global transition towards more sustainable natural resource use. In a recent assessment study the IRP reported, for the first time, material flows for all countries in the world including a territorial and footprint perspective [52].

3.2.2. Framework of Indicators and Focus on Resource Inputs

In the 1990s, the Driving forces–Pressure–State–Impact–Response (DPSIR) framework was established to provide a consistent overall framework for environmental indicators and socio-economic drivers including policy responses [53]. To allow for early policy intervention, pressure indicators are key. Material and energy flow accounts provide pressure indicators for the DPSIR framework. The pressures have well-understood links with production and consumption and with environmental impacts. They represent the physical exchange between nature and society (Figure 2). In order to be policy relevant, the key indicators should describe relevant pressures and be robust against substitution within major categories. Figure 2 shows the main relationships between drivers, pressures and impacts based on socio-industrial metabolism from extraction to final disposal of resources. Indicators for pressures by the volume of resource extraction (material, energy, water requirements) and indicators for specific output-oriented impacts (e.g., global warming potential) are complementary and cannot be substituted for each other [54]. Recently Steinmann et al. (2016) found that the life-cycle-wide input of fossil energy, materials, land, and water ("resource footprints") together explains 82% of the variance of all LCA impact categories covered in a standard database such as Ecoinvent. They conclude that "the plethora of environmental indicators can be reduced to a small key set, representing the major part of the variation in environmental impacts between product life cycles." [55]. While it is clear that substance-specific impacts such as toxicological hazards cannot be precisely predicted by the magnitude of natural resource inputs, the latter basically determines the material throughput and footprints of economies.

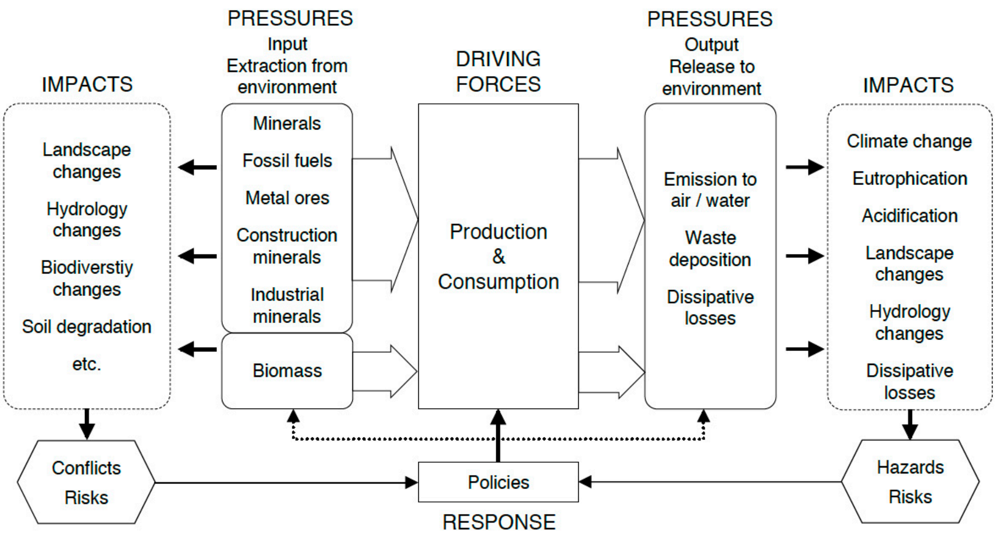

Figure 2. Overview scheme of the physical economy within the DPSIR system [4].

Because countries participate in global trade, the application of a "whole-of-life-cycles perspective" of traded products requires that imports and exports are related to where primary extraction took place to reflect global supply chains. Thus, it is preferable that key indicators are applicable not only within a domestic-economy based, national accounting framework, but also within an LCA framework for selected products. To compare dynamics at the national scale with development at lower scales such as regions, communities, companies and households, it is necessary that the key indicators are consistently applicable across scales (Figure 3).

At each scale, so far, several indicators have emerged to monitor environmental performance. For instance, urban infrastructure supply chain footprints have been developed to describe direct-plus-indirect energy use, GHG emissions and water use of cities [56–59], as well as of production and consumption at the city scale [60]. In addition, sector-specific benchmarks of resource use are useful in comparing infrastructure performance by sectors, e.g., provision of water, energy-efficient housing, transportation, etc. [57]. Such footprints are to a large extent derived from national data or at least combine national with local data.

There is, however, still a large deficit in key indicators of global natural resource use at the national level. For reference purposes and improved consistency of cross-scale natural resource governance this gap needs to be filled.

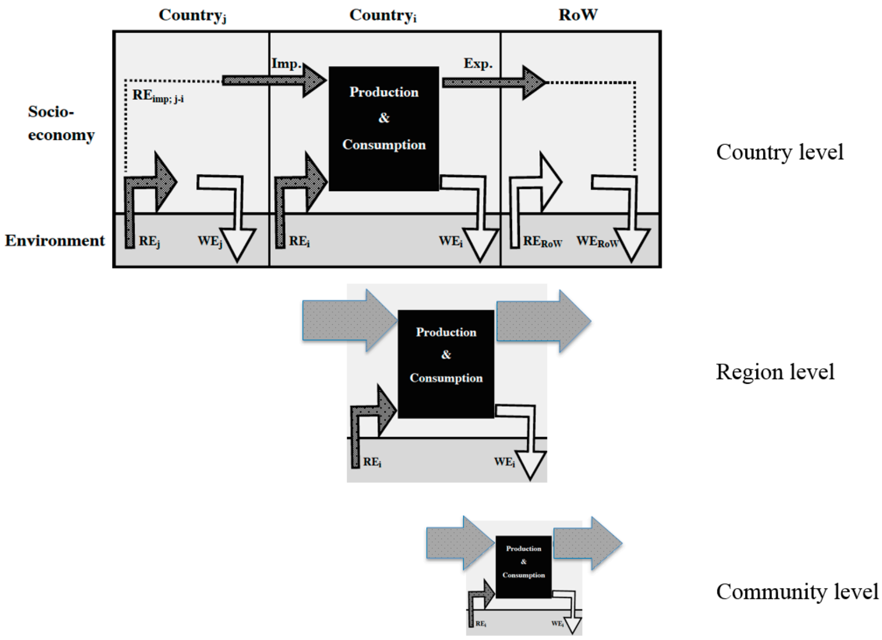

Figure 3. Multi-scale system of production and consumption: the smaller the spatial unit the larger the proportion of horizontal flows and the need to consider up-stream resource flows. (RE: resource extraction, WE: waste disposal and emission release).

3.3. Key Indicators of Natural Resource Use

When comparing resource use and consumption of countries, the use of raw materials, land, water and air are of basic interest (Table 1). Whereas indicators of material input, land use and water consumption represent inputs from the environment to the economy, the use of air may be better represented by the output of greenhouse gases (GHG) emitted to atmosphere (the latter is usually also proportional to inputs of fossil energy). Thus, four major pressures of resource use would be represented (which, according to Steinmann et al. (2016) [55], also might cover more than four fifths of the variance of all output-related environmental impacts).

For each domain of natural resource use, territorial and life-cycle or global perspectives can be applied, the former confining the system boundary to the political boundary of the country, the latter applying a whole of life-cycle system boundary, i.e., focusing on exchanges between nature and society worldwide. When the life-cycle perspective is applied to a country's performance, two questions may be answered: what is the resource use for both production and consumption within the country (including resource use for production of exports), and what is the resource use of the final consumption in the country (excluding the resource use of exports). When the whole life-cycle of all products consumed in a country is measured the indicator is termed "footprint". The literature now speaks of a set or family of footprints [61] which include material footprint, energy footprint, water footprint, land footprint and carbon or GHG footprint (Carbon and GHG emission footprint may differ when the former is defined only on the basis of carbon dioxide and other carbon-based emissions such as methane, while the latter includes also, e.g., nitrous oxide emissions.). Relating the indicators for natural resource use to Gross Domestic Product (GDP) allows monitoring of the progress of decoupling natural resource use from economic development [19].

Table 1. Overview of types and examples of key indicators of natural resource use: territory and life-cycle (footprint) perspective.

	Territory or National Perspective	Global Supply Chain or International Perspective
Materials	Domestic extraction, use and consumption (DEU, DUE, DMI, DMC)	Primary material resource requirements of production (RMI, TMR) and consumption ("material footprint": RMC, TMC)
Land	Artificial land or built-up area	Direct and indirect land use for consumption of biomass-based products focusing on cropland ("cropland footprint")
Water	Water withdrawal	Direct and indirect water consumption (e.g., water footprint)
Air	GHG emissions	Direct and indirect GHG emissions (both carbon and non-carbon emissions)

Note: DE Domestic Extraction, DMI Direct Material Input, DMC Domestic Material Consumption, RMI Raw Material Input, RMC Raw Material Consumption, TMR Total Material Requirement, TMC Total Material Consumption

3.3.1. Materials

Socio-economic material flows and related environmental and social impacts are expected to grow significantly in the coming decades [4,7,19].

Data for domestic extraction of minerals (metals, industrial minerals, construction minerals and fossil fuels) and harvest of biomass (agriculture, forestry, fisheries) are available for more than 200 countries worldwide. A new IRP dataset provides detailed data for material extraction and trade and also aggregated data for main resource categories as well as national indicators such as Direct Material Input (DMI) and Domestic Material Consumption (DMC) and also material footprint (MF) of final demand data and indicators (Data are available at www.uneplive.org.).

A regular update of material flow data would allow monitoring of progress toward material productivity and the assessment of decoupling of material use in production and consumption and economic development. This could be done country-wise or for world regions. In recent years, international comparisons of material consumption and productivity have been provided by UNEP (2011) [19], Dittrich et al. (2012) [62], UNEP 2015 [40] and UNEP 2016 [52].

Accounting for the material footprint of countries requires more comprehensive analysis of the indirect flows of materials associated with imports and exports. This may be done by input-output analysis [63]. For international comparison, such an analysis was performed by Wiedmann et al. (2015) [64] and UNEP 2016 [52] establishing accounts for material footprints (Raw Material Consumption) of countries. EEA 2013 commissioned a comparative sectoral analysis, comprising both used and unused extraction for European countries, thus presenting results for Total Material Consumption [65].

3.3.2. Land Use

Land is quite a specific resource where the limits and the competition of various sectors are obvious, although the driving forces are increasingly distant from their effects.

Global land use change is mainly driven by expansion of urban and agricultural areas and reduction in forest area. As intensity of land use, e.g., in agriculture and forestry, increases, certain areas become severely degraded [3].

Worldwide area of cropland and pasture land as well as forests is regularly recorded by FAO. Data on urban or built-up area is rather poor.

Land footprint analysis, which links major types of land use with a life-cycle perspective to final consumption of products in a country, has been performed so far on the basis of research projects by institutes for single countries or regions such as the European Union (O'Brien et al. 2015 [66] and references therein). Statistical offices have only recently started to adopt the method [67]. The land footprint is determined by either a coefficient approach following the economy-wide material flow analysis method, or by input-output analysis, mainly using a combination of land use data and economic input-output tables. Thus, material, land and carbon footprint can be analyzed consistently [63].

Land use change has been modeled extensively in pursuit of various research questions. Only recently, land use change induced by countries' consumption has also been studied in view of synergies and conflicts in implementing the SDGs [68].

3.3.3. Water Use

Water consumption will lead to increasing scarcity of freshwater with sufficient quality in various world regions [69]. UN-Water (see, e.g., http://www.unwater.org/kwip) and others are reporting on water withdrawal, water scarcity and quality, sanitation, etc. Efficiency of water use has not yet been recorded regularly and could potentially receive higher attention.

Different accounting schemes have been applied and various databases exist to describe water management [70]. Water consumption per capita may be related to water availability of regions or countries, e.g., by the withdrawal-to-availability ratio [69]. UN-Water reports renewable freshwater availability per capita and the percentage of withdrawals from total renewable available water as well as other indicators for all UN countries.

The water footprint concept as developed by Hoekstra and colleagues (2011) [71] in general captures direct and indirect consumptive uses and pollution of water of countries, considering also import- and export-related product water footprints. It comprises three elements: green water footprint (mainly evapotranspiration in agricultural fields), blue water footprint (withdrawals from surface or groundwater without return), and grey water footprint (theoretical volume required to dilute pollutants below environmental quality standards). While the water footprint has been determined for all countries with more than 5 million inhabitants [72], its interpretation is not straightforward. Evapotranspiration of natural vegetation is often much higher than for cropping fields, and also very difficult to measure. Measuring pollution by required dilution volume requires a tremendous amount of data, depending on the number of pollutants and regional standards. Therefore, when considering regular reporting and benchmarking of countries, concentrating on blue water footprint could be an option. This indicator, however, excludes withdrawals which are returned to the same catchment area and thus excludes, for instance, cooling water for power stations which is not evaporated but returned to the river (with increased temperature), a flow which dominates water withdrawals in industrial countries like Germany. Moreover, the water footprint is a pure volumetric indicator which neglects water availability which is becoming serious in various world regions.

A water scarcity index (WSI) has been developed [73] and is available for all countries. It is based on the relation of freshwater withdrawals to hydrological availability of more than 10,000 watersheds [74]. WSI has been developed as characterization factor in LCA. It could also be applied to domestic blue water consumption, thus providing a comparable benchmark for international comparison, and a basis to measure decoupling.

Altogether, territorial accounting methods have been established for material, land and water use. Methods and indicators have been developed to calculate global footprints for the consumption of these resources. International comparisons and databases seem most advanced for the material footprint, which could possibly provide a starting point for regular reporting of global resource use. Nevertheless, institutional improvements are necessary to establish the operational basis for regular data updates and provision of key indicators based on EW-MFA.

Policy demand for target values and research-based reference values for assessment of the status quo and trends with regard to sustainability might further drive the "inspiration cycle" shown in Figure 1 above between research, policy and statistics.

3.4. Information on Resource Use required for Implementing the SDGs

Policy demand for regular monitoring of material, land and water use, and associated footprints, might grow alongside knowledge about how these indicators can support the implementation of the SDGs [1].

The 2030 development agenda comprises 17 goals (Table 2). Many of them relate directly or indirectly to natural resource use. Against the background of the DPSIR framework and socio-economic metabolism perspective, the following groups can be distinguished, reflecting impacts on earth systems, resource flows from nature, their driving forces and societal needs:

- I Goals emphasizing preservation and sustainable use of earth systems 13 (climate), 14 (oceans), 15 (terrestrial ecosystems)
- II Goals emphasizing sustainable supply by resource sectors 2 (food, agriculture), 6 (water), 7 (energy)
- III Goals emphasizing social and technical improvements of the economy 1 (poverty), 8 (economic growth), 9 (infrastructure, industries), 10 (inequality), 11 (cities), 12 (consumption and production)
- IV Goals emphasizing cultural improvements of society 3 (health), 4 (education), 5 (gender), 16 (peace)

The main question for policy is how goals II–IV can be achieved without compromising the life-sustaining basis of natural resources and ecosystems reflected by goal group I. In other words: How can sustainable resource use be reached which preserves and improves the living environment while supporting progress towards goal groups II–IV? Concrete modes and options for implementation must be considered as well as potential conflicts and synergies. Pursuit of goals in group II requires increased efficiency in the use of agricultural resources, water and energy, comprising technical and organizational improvements at local to regional scales. Information on the resource efficiency of food systems and supply technologies is needed. Whether sectoral improvements lead to overall improvement and not just transregional problem shifts will also require monitoring of resource footprints at national level.

The implementation of goals in group III seems most challenging. The conventional approach of alleviating poverty, promoting economic growth, providing higher welfare for all, generating better utilities and prosperous industries, and allowing consumers to satisfy their wishes, has been and still is associated with growing consumption of natural resources. Thus, the pursuit of group III goals is inherently in conflict with the goals of group I. Sustainable resource use must build a bridge, and the increase of resource productivity and the decoupling of resource use with well-being will be key towards this end. Monitoring progress thus requires resource consumption to be recorded, including global resource use by national economies, and compared against socio-economic progress indicators. Monitoring the Four Footprints will essentially contribute to evaluating the effectiveness of cross-scale resource policies at country level.

In contrast, the implementation of goals in group IV seems synergistic with more sustainable use of natural resources and therefore also with reaching goals in groups I–III. Health requires a healthy environment; education widens perspectives and provides the basis for innovation; empowering women often accompanies wiser use of resources; and peace is a precondition for reliable living conditions, while unsustainable resource use may lead to or foster military conflicts, more sustainable resource use will be fostered by progress towards those goals, and potentially also vice versa.

It is important to note that goals of group I—climate stability, biodiverse and functioning ecosystems—cannot be attained without more efficient and sustainable use of natural resources across scales, in particular without significant progress towards more sustainable consumption and production systems, at the level of infrastructure, cities and whole economies.

Table 2. SDGs with explicit relevance for resource use.

SDG	Key Resource Strategy	Challenge—Risk	Information Required (Selection)
Goal 1. End poverty in all its forms everywhere	Clarify land ownership and property rights in particular for the poor	Property rights and land ownership—if legally established—must be accompanied by responsible use and policies to avoid limitless resource extraction	Land registers and transparency in foreign investments
Goal 2. End hunger, achieve food security and improved nutrition, and promote sustainable agriculture	Sustainable intensification of agriculture Minimization of food waste Shift to more healthy diets	Local limits to intensification may lead to expansion of intensively cultivated land and loss of biodiversity	Good agricultural practice for local resource management; Data on biomass flows, including waste; self-supply ratio and physical trade balance; land footprint and reference values for assessing its sustainability
Goal 3. Ensure healthy lives and promote well-being for all at all ages	Human health relies on a healthy environment	A more sustainable natural resource use tends to result in a healthy environment. However, both may become the privilege of the rich. Therefore, this goal may not be reached in contradiction with Goal 12.	see Goal 12.
Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	Better education fosters independence Natural resource use ("brainware instead of hardware")	Better education is therefore synergistic with more sustainable resource use. It also leads to higher incomes which may increase resource consumption.	Information on resource consumption, including resource footprints, resource productivity, and good practices of sustainable resource management from local to national and global
Goal 5. Achieve gender equality and empower all women and girls	Gender equality tends to foster more sustainable use of natural resources	Gender equality is therefore synergistic with more sustainable resource use	As for Goal 4
Goal 6. Ensure availability and sustainable management of water and sanitation for all	Water use efficiency	Resource-intensive infrastructure for water supply and sanitation Overuse of water despite high use efficiency	Information on resource efficient technologies; Water balances for regions; water footprint weighed with water scarcity
Goal 7. Ensure access to affordable, reliable, sustainable, and modern energy for all	Energy efficiency Shift to renewable energies	Problem shifting by growing use of certain renewable energies such as those based on plants	Reference values for resource footprints of energy technologies (e.g., RMI per kWh); Resource Footprints at the national level covering energetic and non-energetic material flows, land use, water withdrawal and GHG emissions to detect problem shifts
Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	Decoupling of both economic value creation and employment from resource use	Growing resource consumption despite relative decoupling Shifts of resource-intensive industries to resource extracting countries	Monitoring of territorial and global resource use of national economies; including all resource footprints, international comparison of resource productivity and resource consumption per person; reference values for resource footprints, in particular material footprint

Table 2. *Cont.*

SDG	Key Resource Strategy	Challenge—Risk	Information Required (Selection)
Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	Resource efficient infrastructure Resource efficient industries	Build-up of infrastructure in DCs and maintenance in ICs in a highly resource-intensive mode; Copying technologies of IC by DCs may multiply problems	Information on resource efficient infrastructure; Information on development and operation of resource efficient industries and companies, incl. sectoral resource footprints of their products
Goal 10. Reduce inequality within and among countries	Foster resource efficiency in order to allow poorer countries and people to attain well-being and welfare more easily and less burdensome	Resource efficiency increase also leads to enhanced competitiveness of countries and thus may tend to increase inequality. This goal can only be implemented together with Goal 12.	See Goal 12.
Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable	Same as for Goals 2, 6, 7, 8, 9 plus resource efficiency in buildings and transport	Cities will always depend on their "hinterland" and trade across cities and regions for resource supply; problem shifting may occur to regions outside or between resources	Information on resource efficiency in the building and transport sector and integrated city planning Information on resource footprints for the city as a whole and for community-wide infrastructure
Goal 12. Ensure sustainable consumption and production patterns	Same as for goals 2, 6, 7, 8, 9 plus decoupling of well-being and resource use	Growing number of net consuming countries, often far away from the locations where resource extraction and refining poses environmental and social problems	Monitoring all resource footprints, international comparison of resource productivity and consumption per person; reference values for sustainability assessment; Policy programs to foster economy-wide sustainable resource management, incl. aspects listed for goals 2, 6, 7, 8, 9
Goal 13. Take urgent action to combat climate change and its impacts	Enhance resource efficiency Promote sustainable consumption and production	Higher material and energy efficiency is usually synergistic with mitigation of GHG emissions; but not all mitigation and adaptation measures may be resource efficient	Information on potentials of material and energy efficiency measures for climate protection for infrastructure, production and product technologies; monitoring the Four Footprints for technologies and whole countries
Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development	Fishing quota and ocean conservation parks Promote sustainable consumption and production	Good ocean management practice and conservation areas may be overridden by growing demand for resource use Specific Goal 14 strategies will only work when Goal 12 strategies are effectively implemented	Good practice of management of ocean resources. See Goal 12: providing data on overall resource use, including from oceans

Table 2. *Cont.*

SDG	Key Resource Strategy	Challenge—Risk	Information Required (Selection)
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss	Proper local to regional land management Conservation areas Promote sustainable consumption and production	Good land management practice and conservation areas may be overridden by growing demand for resource use Specific Goal 15 strategies will only work when Goal 12 strategies are effectively implemented	Good local resource management practices Data on land potential, including both biomass production and biodiversity Monitoring different types of land use at global, national and regional levels See goal 12: providing data on overall resource use including from agriculture and forestry
Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	Good policy practice	The goal tends to be synergistic with sustainable resource use Overuse of natural resources tends to induce or worsen conflicts Progress towards Goal 12 might help to mitigate conflict pressure about resources	Transparency on resource use across levels

Table 2 provides an overview of key resource strategies which may help to approach the SDGs, the challenges (leading to potential conflicts between goals) and information required to enable actors at different scales to make knowledge-based decisions for more sustainable resource management.

Improvement of the information base, including on the resource effectiveness of technologies, organizational changes and policy instruments is required across scales. Further development towards synergistic pursuit of the SDGs via multi-scale sustainable natural resource use will require progress in particular on the monitoring of global resource use at the national and sub-national level. Towards this end, institutional development is needed, as also requested by SDG 17.

4. Needs for Institutional Development

The implementation of the SDGs requires rethinking the way global society uses natural resources. New policy issues are emerging which can be adopted by existing institutions or may require the establishment of new ones. With this article we are starting a debate and various options will have to be seriously considered. The options that we describe in the following are by no means exhaustive but aim to cover essential and complementary elements of a future global sustainable resource use governance. Basically, further development towards global sustainable resource management would have to improve the knowledge base.

4.1. Monitoring Global Resource Use

Monitoring global resource use and benchmarking countries regularly regarding their resource consumption and productivity would be an effective instrument not only to improve the knowledge base, but also to foster competition among countries towards sustainability (An example for benchmarking of countries with regard to their resource productivity is the European Resource Efficiency Scoreboard: http://ec.europa.eu/eurostat/web/europe-2020-indicators/resource-efficient-europe). If authoritative and legitimate information were to be provided, the monitoring would be conveyed by international governmental organizations. The status of natural resources and the global environment has been reported in the GEO reports by UNEP [75]. The use of material resources and the footprints of countries or country groupings have been reported for European countries by the EEA [62], for OECD and BRIICS countries by the OECD [76], and globally by the IRP [52]. The latter report could be taken as a pilot to provide key elements for regular reporting. As an option, a regular reporting mechanism on global resource use of countries, including their resource productivity (to monitor progress of decoupling) and natural resource footprints (to monitor progress towards sustainable resource consumption) could be established within the UN system. The IRP could potentially supervise the reporting and assist with assessment. Further outlets of key indicators could be, for instance, the Green Growth Knowledge Platform [77]. Ultimately, countries' reporting capacity needs to be supported so countries regularly report their economic accounts and satellite accounts for natural resource use, emissions and waste. The UN statistical division could provide the necessary training through its regional economic and social commissions in Asia and the Pacific, Africa, and Latin America and the Caribbean.

4.2. Establishment of an International Database on Global Resource Use

The need for an international database for global natural resource use has become obvious in the past decade [78]. Such a database could be aligned with the Eurostat Data Centre for Natural Resources [79] and the OECD database on material flows. Different institutions such as the Vienna University of Business and Economics, the Institute of Social Ecology in Vienna, the Wuppertal Institute and the Institute for Energy and Environment Research (IFEU) in Germany, the United States Geological Survey (USGS), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) of Australia and Nagoya University of Japan have hosted global datasets. Based on existing datasets from these institutes, the most recent and comprehensive database for national MFA and indicators was compiled for an assessment study of the IRP [52] for global material flows and resource productivity. Institutional settings will have to be explored in order to organize regular updates with rigorous quality control within an international government-based framework. Ideally, a Global Resource Data Center could be established to provide national MFA data for all countries including indicators of material use and resource productivity of production and consumption, including the Four Footprints, specifying resource groups, covering both used and unused extraction, and providing information on critical and otherwise relevant materials, both primary and recycled.

4.3. Development of an International Competence Center on Sustainable Resource Management

An information hub for governments, NGOs and industry is needed to create the necessary knowledge base for global sustainable resource management at different scales. This would involve coordinating the development of an international protocol for national material flow accounts and MFA indicators—based on existing Eurostat and OECD guidelines—to monitor natural resource consumption, resource footprints and resource productivity. With regard to lacking statistics and methodological know-how in many developing countries, such a center would essentially contribute to capacity building in countries of the Global South. The competence center would also initiate, supervise and interpret studies to promote global sustainable resource management, and would develop target proposals for the assessment of sustainable natural resource consumption such as, for example, a safe operating space corridor for global natural resource extraction. To support sustainable solutions, the competence center would provide compilations of good practice examples of natural resource policies and deliver studies about the effectiveness of certain instruments, policy tools and measures.

4.4. Development of a Global Sustainable Resource Management Program

Under the auspices of the United Nations, and aligned with ongoing activities of UNEP, UNIDO and UNICEF, complementing and providing synergies with UN conventions on climate change, desertification, biodiversity, and taking up outcomes of institutions such as FAO, WMO, and WTO, an international policy program to foster global sustainable resource management could be developed. Such a program could be based on the achievements of the International Resource Panel which may continue to serve as an advisory body within such a program. The new program would support and help implement initiatives such as the Green Economy initiative of UNEP [80], the Green Growth Strategy of the OECD [81] and the Global Solutions Network [82]. Such a policy program would require a legal basis in the form of an International Convention. A promising institutional home for a global SRM program is the newly formed United Nations Environment Assembly (UNEA) which, jointly with the High Level Political Forum, could draft a mandate and take the lead in developing an International Convention for Sustainable Resource Management.

5. Conclusions

Our review has aimed to fill a gap in the scholarly literature on natural resource use governance and created new insight that is required to go beyond traditional local and community based natural resource governance. We demonstrate that the management of natural resource use stretches across different scales, from local and regional to national and international and describe the need for new data and indicators to inform policy. As we have shown, significant progress has been made in recent decades in developing methods and indicators to measure natural resource use of countries, i.e., their direct use of material, land, water and GHG emission and footprints. Various countries have started to develop natural resource policy programs, both to enhance supply security and to increase resource efficiency. We have addressed strategies in pursuit of sustainable natural resource use, such as resource efficient production and consumption, which will be a prerequisite as well as synergistic for the implementation of the SDGs. We find that the knowledge base for global sustainable resource management at different scales needs to be improved. To achieve this, existing institutions would need to adopt new agendas and tasks that improve the ability to manage natural resources more sustainably. In addition, we find that new institutions may be required at the global scale that actively engage and communicate with the network of national and subnational constituents. The options presented and discussed in our research are not exhaustive but represent a unique set of possible measures at the global scale that would be comprehensive and complementary. In particular, regular monitoring of global natural resource use, a consolidation and regular update of the International Resource Panel (IRP) dataset for material flows, an international competence center, and an international policy program based on a United Nations convention for sustainable natural resource management are possible milestones on the way towards a sustainable future for natural resource use. We argue that the International Resource Panel is well positioned to support the process described to improve global and multi-scale resource governance, including monitoring and estimating future trends (to enable early warning), assisting with institutional development, and thus strengthening the science–policy interface.

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